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SAVING COAL IN BOILER PLANTS

BY

HENRY KREISINGER

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SAVING COAL IN BOILER PLANTS.

By HENRY KREISINGER.

INTRODUCTION.

This paper, published by the Bureau of Mines in the interest of more efficient utilization of fuels in this country, gives suggestions as to what can be done in the boiler room to save coal. It covers the field between two other Bureau of Mines publications, Technical Paper 80, "Hand Firing Soft Coal Under Power-Plant Boilers," and Bulletin 97, "Sampling and Analysis of Flue Gases." It is written for the fireman, the engineer, and the owner of the small or medium size plant, which is, as a rule, hand fired.

The large plants usually have efficient and modern equipment, are mechanically fired, and are operated under the direction of technically trained and experienced men who hardly need such general suggestions as are given in a paper of this character. The small and the medium size plants, of which there are a very large number, have less efficient equipment, and, in addition, their size makes it inadvisable to retain a highly trained boiler-room operator. For these reasons fuel losses are likely to be higher in the smaller plants, and there such suggestions as are made in this paper will prove of greatest benefit. In these plants the hope of decreasing the losses lies entirely in the fireman, the engineer, and the owner or manager. These three men must closely cooperate if the desired results are to be obtained. The fireman and the engineer should give good will and steady endeavor; the owner or manager of the plant should encourage the firemen and the engineer to save coal, and should show appreciation of their efforts.

The fireman should keep in mind that his duty is to make steam and not merely to burn coal. He must be willing to learn and be patient with his progress, whether studying printed suggestions or trying such suggestions in practice. He should not be discouraged if he has difficulty in understanding them or if his progress is slow. He must make honest effort. He should bear in mind that there is no royal road to knowledge and skill.

The engineer should cooperate with the fireman full-heartedly; complete cooperation is absolutely necessary if their efforts are to be successful. Usually, the engineer will decide what method should be tried. He should endeavor to give each method an honest trial and study the results impartially before making conclusions. In nearly every plant the engineer can find ways of saving coal, if he seeks for them, and it is his duty to find the best methods and see to it that they are put into practice. He should take pride in any real success that has been attained through his effort and perseverance. He should devote part of his time to reading and studying literature on the economical operation of power plants, particularly any articles on saving coal. It is true that all the suggestions made in such articles will not apply to the plant where he is employed, but doubtless many of them can be readily adopted. Above all, and for his own sake, he should avoid being indifferent.

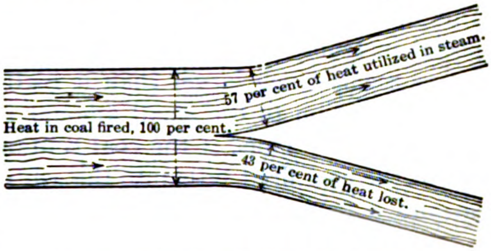
The owner, or manager, of the plant should encourage the fireman and the engineer in their efforts to save coal by providing them with the necessary tools and instruments, and should show his appreciation of any improvement in the efficiency of the plant by a suitable reward, preferably in wages or bonus payments. Such appreciation is important and necessary if the good work in the boiler room and engine room is to be continued.

These principles and most of the suggestions made in this paper apply equally to mechanical stoker plants.

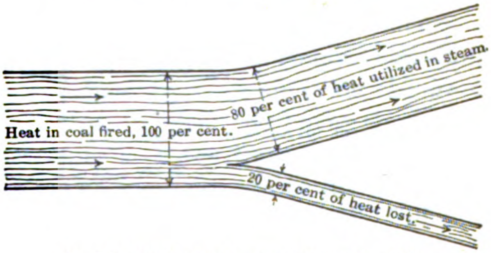
WHAT CAN BE DONE IN SAVING COAL.

In the average steam plant, 57 per cent of the heat in the coal burned under the boilers is utilized in making steam and 43 per cent is lost—that is, of 100 tons of coal fired under the boiler, 57 tons is actually utilized in making steam, and 43 tons is not used, from various causes. Some of the large plants get results considerably better than this, but many of the small plants get poorer results. Records of the best performances show that about 80 per cent of the coal burned was actually utilized in making steam, and, although such high results can not be obtained with the existing apparatus or equipment in some plants, a requirement of 65 to 70 per cent is justifiable. The diagrams in figure 1 show what is being done and what is possible. Raising the average efficiency from 57 to 67 per cent means the saving of about 15 tons of coal out of every 100 tons. At present about 300,000,000 tons of coal annually are necessary to supply all the steam plants in this country, whereas with proper care taken in operating these plants only about 255,000,000 tons would be needed, making a saving of about 45,000,000 tons.

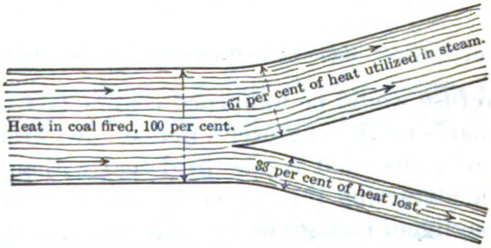
How are these steam plants to increase their average efficiency from 57 to 67 per cent? The method is simple, and easy to understand, although to many it may seem slow in bringing results and perhaps tedious to follow. It is the application of the essential principles already mentioned—namely, good will and steady honest effort on the part of the fireman and the engineer; and encouragement and appreciation on the part of the owner or manager of the plant. Only these means will bring the desired results. There is no miraculous powder that when dissolved in water and sprinkled over coal will make it give up more heat and produce more steam. All powders sold under such pretenses are frauds. Also, there are no patented devices that when attached to the boiler will automatically make large savings without the effort of the fireman or the engineer. Many patented fuel-saving devices have elements of merit, but they must have careful, intelligent attention to do good work. It has been said that there is no royal road to knowledge; if a man wants to understand, he has to study, learn, and work. It can be said equally well that there is no royal road to saving coal; the engineer and the fireman must study, learn, and work, each in his own way. Careful, sincere endeavor by the fireman and the engineer and the hearty cooperation of the owner are absolutely essential to success in any campaign for saving fuel. These requirements must be furnished by the men of the plant; they can not be bought on the market. On the following pages are given suggestions as to how these requirements should be applied.


57 per cent of heat utilized in steam.
Heat in coal fired, 100 per cent.
43 per cent of heat lost.

A. The average boiler plant does like this.


80 per cent of heat utilized in steam.
Heat in coal fired, 100 per cent.
20 per cent of heat lost.

B. The best plants are doing like this.


67 per cent of heat utilized in steam.
Heat in coal fired, 100 per cent.
33 per cent of heat lost.

C. The average plant can and should do like this.

FIGURE 1.—Diagrams showing possible improvement in efficiency at average boiler plants.

HOW HEAT IS LOST AND COAL WASTED.

Figure 1 shows the amount of heat lost in the boiler plant, but does not show how it is lost, and what can be done to reduce the loss. The way the heat is lost is indicated, in a general way, in figure 2. That is, in the average plant, about 4 per cent of the 43 per cent lost goes down with the ashes, 4 per cent is lost by radiation, and 35 per cent goes up the stack. The heat loss up the stack is the greatest in the boiler room, and the efforts of the fireman and the engineer should be centered on reducing it.

THE ASH-PIT LOSS.

In the hand-fired plant the ash-pit loss is usually small because unburned combustible is easily detected in the refuse. If the ash contains much combustible, it can be readily seen without the aid of special instruments; also the loss from partly burned coal or cinder always seems much larger than it really is, because the fireman sees it in proportion to the small amount of ash formed rather than to the coal fired. Thus, if the coal contains 10 per cent ash, and 5 per cent of the coal fired falls into the ash pit, the refuse will be 10 parts ash and 5 parts unburned coal. In other words, one-third of the refuse would be unburned coal, a fact that could not escape the fireman's or the engineer's notice. No fireman would keep on wheeling out refuse that is one-third coal without trying to improve his firing or attracting the engineer's attention to it, and even if he should be negligent enough to do so, he would very likely be reprimanded by the engineer or the owner, as soon as they noticed it. On the other hand, if the loss is small the fireman should receive some pleasant word of appreciation to encourage him in his effort. Deserved recognition will awaken interest in his work and pride in his skill. Suggestions for improvement are much more effective when they are made in a way that appeals to a man's pride.

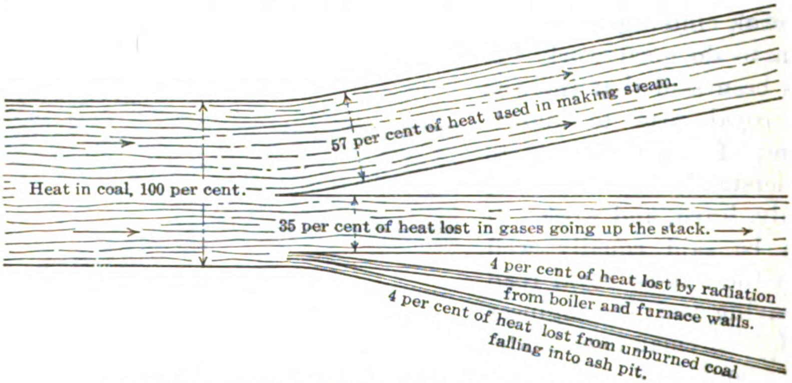

57 per cent of heat used in making steam.
Heat in coal, 100 per cent.
35 per cent of heat lost in gases going up the stack.
4 per cent of heat lost by radiation from boiler and furnace walls.
4 per cent of heat lost from unburned coal falling into ash pit.

FIGURE 2.—Where the heat goes in the average boiler plant.

CAUSES OF HIGH ASH LOSS, AND REMEDY.

The most common causes of a high ash loss are improper cleaning of fires, bare spots, and useless poking of fires. If the cleaning is not properly done, a large quantity of combustible is pulled out of the furnace with the clinker and ashes. After cleaning, if there is not enough burning coal left in the furnace to cover the grate completely, and fine coal is fired, some of it sifts into the ash pit. Therefore, when fires are cleaned care should be taken that there is enough burning coal on the grate to start a good fire after the cleaning is completed. Effort should also be made to run the fires in such a way that few cleanings are necessary, and that these are done when there is little or no load on the boiler. Fires can be run longer without cleaning if they are built gradually with small and frequent firings. Heavy firings immediately after cleaning have a tendency to start troublesome clinker. In industrial plants a day's run should be started with a thoroughly clean fire, built gradually to full steaming capacity. Perhaps in no other kind of work is a good start of such advantage as in running fires. A more thorough discussion of methods of cleaning fires is given on page 31 of Bureau of Mines Technical Paper 80, "Hand Firing Soft Coal Under Power-Plant Boilers."

Frequent poking of fires may cause an excessive loss from coal falling into the ash pit. Also the poking increases the tendency of the coal to clinker, thereby making necessary more frequent cleaning.

In some fires high ash loss is caused by bare spots on the grate. The firings may be so far apart that the fuel bed burns through in places. When the fireman attempts to cover these bare places the fine coal sifts into the ash pit. The remedies are to fire frequently and place coal on the thin spots before they burn through and form holes.

THE RADIATION LOSS.

The radiation from the boiler is usually small if the boiler has been properly set, and little can be done to reduce it. Of course, all steam and hot-water pipes should be covered with insulating material.

THE LOSS UP THE STACK.

In the average boiler plant, 35 per cent of the heat in the coal burned under the boilers is lost with the stack gases. That is, out of every 100 tons of coal burned under the boilers, the heat of 35 tons literally goes up the stack. It is this loss that can be greatly reduced and every effort should be made to do so.

The stack loss is so large because its magnitude can not be readily detected. Nobody can tell how much heat is going up the stack simply by looking at the stack. The density of the visible smoke is no indication of the amount of heat being lost. The magnitude of the loss can be found only by the use of special instruments and carefully kept records.

By far the largest part of the stack loss is heat held by the gases because of the high temperature at which they leave the boiler. This part of the loss is unduly large when too much air enters the furnace and the boiler setting; it can be greatly reduced by decreasing the excess of air and by lowering the temperature of the gases leaving the boiler. To burn 1 pound of coal requires about 14 pounds of air. This air enters the furnace at atmospheric temperature and leaves the boiler at a temperature about 500° F. higher. It carries with it all the heat it absorbed in being heated through this temperature range of 500 degrees. Each pound of air absorbs approximately one-fourth of a heat unit (B. t. u.) for each degree of temperature rise. Therefore, each pound of air, in being heated 500 degrees, absorbs $\frac{500}{4}=125$ heat units. Fourteen pounds of air absorbs $14\times125=1{,}750$ heat units. If, instead of 14 pounds of air being admitted for each pound of coal fired, 28 pounds is admitted into the furnace, the heat carried away by this weight of air will be $28\times125=3{,}500$ heat units, or twice as much as in the furnace using 14 pounds. Again, if the gases should leave the boiler at a temperature 1,000 degrees higher than atmospheric they would carry away twice as much heat as gases heated to only 500 degrees, and one pound of gas would carry away $\frac{1000}{4}=250$ heat units. Therefore, the amount of heat carried away by the flue gases depends directly upon the weight of air entering the furnace and the temperature rise. Air entering the furnace in excess of about 14 pounds to a pound of coal burned is not necessary to good combustion, and the heat it carries away when leaving the boiler is wasted.

The stack loss also includes the heat units in the unburned combustible gas and in the visible smoke. This part of the loss is due to the lack of enough air at the right time and place to burn the gases completely. Thus one part of the stack loss is due to excessive supply of air, and the other part to insufficient supply of air. Hence, there is always the possibility that by reducing one part of the loss we may increase the other part. However, in the average plant the loss from excess air supplied to the furnace is far larger than the loss from incomplete combustion, and the sum of the two can be greatly reduced by decreasing the excess of air. In many plants both parts of the stack loss can be reduced by more careful firing.

METHODS OF DETERMINING STACK LOSSES.

ORSAT APPARATUS.

The most direct method of determining the stack losses is by chemical analysis of the flue gases, and measurement of their temperature. A fairly complete analysis of the gases can be made with an Orsat apparatus. From the results of such an analysis, and the temperature, the magnitude of the loss due to large excess of air and also the loss due to incomplete combustion can be found. In large plants it will pay to hire a trained man to make analyses of the gases and to direct the firemen. In the smaller plants the engineer should become thoroughly skilled with the Orsat apparatus, and use it. By using the Orsat apparatus intelligently he can learn more about proper methods of firing and operating the boilers than in any other way, and he can earn his salary better than by performing less important duties, such as he is often called on to do.

In many plants of 1,000 to 2,000 horsepower capacity, the engineer is required to be a pipefitter, a millwright, a blacksmith, a machinist, and many other varied and often trivial duties are placed on his shoulders. These secondary duties frequently keep him so busy that he has scarcely any time to find out how the plant is running and how much fuel it uses. Making the plant develop the needed power with the least amount of coal should be the engineer's chief and, perhaps, only duty, and as a general proposition, it will pay the owner to make it so. When a plant uses $50 to $100 worth of coal a day, efforts to save 10 per cent of it will pay. The days of low-priced coal are gone, probably never to return.

Many engine operators believe that the Orsat appartus is too delicate and the gas analysis is too difficult for anyone but a skilled chemist, and for that reason they are diffident about trying it. As a matter of fact the Orsat is a much simpler instrument and much easier to manipulate than a steam-engine indicator, which most engineers know how to use. With careful effort an engineer ought to be able to learn to use an Orsat in one or two days. An Orsat apparatus is much cheaper than an indicator outfit, costing only about one-third as much, and as far as saving coal is concerned is much more useful than the indicator.

For studying the merits of different methods of firing, "grab" samples of the furnace gases taken at different intervals of time after firing will be found useful. For the determination of the chimney losses or to test the skill of different firemen, the "time" sample, collected over long periods, should be used.

SAMPLING AND COLLECTING FLUE GASES.

For the ordinary work in the boiler room the simple open-end gas sampler is the most convenient to use, and when carefully placed gives good results. The sampler can be made of standard ¼ or ⅛ inch iron pipe, placed with the free open end in the center of the gas stream. If the sampler is placed in the uptake, the opening of the sampler should be so placed that the sample will be affected as little as possible by the damper changes. Figures 3 and 4 of Bulletin 97, Bureau of Mines, "Sampling and Analysis of Flue Gases," show a good position for the sampler in the uptake. Figure 12, on page 21 of

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the same bulletin, shows the position of the sampler in the third pass of a cross-flow, water-tube boiler, the sampler being inserted through a cleaning hole in the side of the setting. In the parallel-flow type of boiler the sampler can be inserted through one of the hollow staybolts.

The gas sample can be drawn into a special collecting bottle or directly into the Orsat apparatus. For a detailed study of what happens in the furnace the sample should be taken directly into the Orsat, and as many samples analyzed as possible. When this is done the sampler should be of the smallest pipe available and the connections should be so short that the sampler and the connection hold only a small volume of gas. Before a sample is taken for analysis, the air or gas in the sampler should be drawn out. In studying the results of a gas analysis due allowance should be made for leakage of air into the setting between the furnace and the place of sampling.

Complete information on the sampling, collecting, and analyzing of flue gases is given on pages 7 to 34 of Bulletin 97. A method of calculating the stack losses from the analysis is given on pages 35 to 39 of that bulletin.

AUTOMATIC CARBON-DIOXIDE RECORDERS.

For determining the amount of excess air entering the furnace an automatic carbon-dioxide recorder can be used. The carbon-dioxide recorder costs considerably more than an Orsat gas-sampling apparatus and does not indicate the incompleteness of combustion. The carbon-dioxide indication should be checked from time to time with an Orsat apparatus. The recorders have the advantage that, after proper adjustment, they run automatically with little attention from the operator and make a continuous record from which the loss due to excess of air can be approximately calculated. A description of the various makes and directions for operating them are given in Bulletin 91, Bureau of Mines, "Instruments for Recording Carbon Dioxide in Flue Gases."

SIGNIFICANCE OF FLUE-GAS ANALYSIS.

Large excess of air is indicated by low carbon-dioxide content and high-oxygen content. Incomplete combustion is indicated by carbon monoxide. An average of 10 to 12 per cent of carbon dioxide in the flue gases can be considered as good performance, provided the percentage of carbon monoxide is small. Some boiler furnaces can be run with the gases containing as high as 14 per cent carbon dioxide without carbon monoxide appearing, whereas in other furnaces the gases may show a considerable amount of carbon monoxide even with 10 per cent of carbon dioxide, particularly with large firings. As a general rule, the monoxide content in the flue gases should not be allowed to reach one-half of 1 per cent. It should be remembered that carbon monoxide is only one of the combustible gases; there may be hydrogen (H_2) and in small furnaces even a small amount of methane (CH_4). The actual total loss from incomplete combustion may be twice as large as that indicated by the percentage of carbon monoxide. Methods of calculating this loss are given in Bulletin 97, on pages 38 to 43.

CAUSES OF LARGE EXCESS OF AIR AND REMEDY.

The causes of large excess of air are: Holes in the fire, frequent raking or slicing of the fire, too large openings in the dampers of the firing door, badly warped fire doors that can not be shut tightly, leaky settings, and firing doors kept open too long.

HOLES IN THE FIRE.

Holes in the fire are by far the most common cause of large excess of air in the flue gases and large losses of heat up the chimney. Such holes are entirely within the control of the fireman; therefore it is evidently his duty to prevent them. The forming of holes can be avoided by firing frequently and placing the coal on the thin spots of the fuel bed. The more frequent the firing the less chance there is for holes to form. Complete directions for firing are given in the first 20 pages of Technical Paper 80, Bureau of Mines, "Hand Firing Soft Coal Under Power-Plant Boilers."

It often happens that if the fireman keeps the fire level by small and frequent firings, the steam pressure rises to the blowing-off point. The rise of the steam pressure is a result of two causes—more coal is burned than is needed, and there is no cooling effect from air entering through holes in the fuel bed. Then the fireman, in order to avoid wasting of steam, usually fires less often and thus lets the fire burn out in spots. As soon as he discovers that the fire is burning through, he should take steps to keep the fire free from holes. If he must put on more coal than is necessary to keep the pressure up, he should reduce the draft by partly closing the uptake damper, so that the coal will burn more slowly. In other words, the amount of coal fired should be adjusted to the demand for steam, and the volume of air flowing through the fuel bed should be adjusted by the draft damper to the amount of coal that must be burned.

The fireman must grasp this principle and understand it. For every pound of coal burned on the grate 7 pounds of air must be made to flow through the burning bed of coal, and through it only. Most of the air that flows into the furnace through a hole in the fire does not aid in burning the coal surrounding the hole. The stream of air merely absorbs a large quantity of heat and carries it

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out through the stack. The amount of air flowing up through a level bed of burning coal depends on the draft; the stronger the draft the more air flows through the fire and the faster the coal is burned. Also, the weaker the draft the less air flows through the fuel bed and the slower the coal burns. Each 7 pounds of air burns or gasifies one pound of coal in the fuel bed; if the air is supplied at a faster rate than 7 pounds to a pound of coal, the fire will burn out, and holes are formed. If, on the other hand, the air is supplied more slowly than the coal is fired, the coal will accumulate and pile up into a thick bed.

PROPER REGULATION OF DRAFT ESSENTIAL.

Therefore, proper regulation of the draft is very important for efficient burning of coal. In order to enable the fireman to regulate the draft properly, the uptake damper connection should be made in such a way that he can handle this damper from the floor in front of the furnace, and handle it easily and often. Also, the furnace should have a draft gage, so that he can adjust the damper to obtain the draft desired. The engineer should see that the boilers have the proper damper connections within convenient control of the fireman. Two kinds of damper connections are shown on pages 22 and 23 of Technical Paper 80, "Hand Firing Soft Coal under Power-plant Boilers." The owner of the plant should encourage the engineer and the fireman in their efforts to burn his coal efficiently, by providing draft gages and the necessary materials needed for connections.

The draft should be changed gradually; the damper should not alternately be nearly closed and then fully opened. In burning coal there is nothing more wasteful than sudden changes in draft.

THE DRAFT GAGE.

The draft gage gives the fireman valuable information as to the condition of the fuel bed. If the indication is too high he may be sure that the fuel bed is too thick or that there is a large accumulation of clinkers. If the indication is too low he should suspect there are thin spots or holes in the fire, and cover them.

The draft gage is as necessary for efficient operation of boilers as the pressure gage or the water gage. If the steam pressure is too high the safety valve blows off and lets the fireman know that he is burning too much coal. On the other hand, if there are holes in the fire, the air entering the furnace through the holes may carry away more heat through the stack than would be blown off through the safety valve without exciting the fireman's suspicion. If there is a draft gage connected to the furnace, the low indication on the gage would warn the fireman.

KEEPING THE FUEL BED LEVEL.

Frequent raking and slicing of the fire causes large losses of heat up the stack, because whenever the fireman rakes or slices the fires a large excess of air enters the furnace through the open fire doors. The firing should be done in such a way that raking and slicing becomes unnecessary. The fire should be kept level by firing small charges at short intervals and placing the coal on the thin spots. Small and frequent firings largely prevent the forming of a crust and of high places, which would have to be broken and leveled with a rake. Slicing can be reduced to a minimum by keeping the fire rather thin—5 to 6 inches gives good results in the average hand-fired plant.

A thick fire and accumulations of clinker on the grate may cause large stack losses because of the large excess of air. Such conditions in the fuel bed tend to increase the draft over the fire, thereby causing entirely too much air to flow into the furnace through the openings in and around the firing doors. The high draft in the furnace also increases the leakage of air into the setting. It is well to add that thick fires are the most common cause of troublesome clinker. For a discussion of thick fires and the causes and remedies for clinker, the reader is referred to Technical Paper 80, pages 29 and 38.

It is plainly a part of the duty of a good fireman to avoid the losses caused by frequent poking of fires, thick fuel beds, and accumulations of clinker, and it is up to him to "do his bit."

LEAKAGE OF AIR INTO THE SETTING.

Leakage of air into boiler settings is probably the next largest cause of excessive chimney losses. In the average plant about one-third of the gases in the breeching is air that has leaked into the setting; in many small plants the leakage is even higher; and even in a well-kept plant it runs one-tenth to two-tenths. Most of the leakage is through cracks in the walls, around and through cleaning and access doors, and through joints between the metallic parts of the boiler and the masonry. The walls themselves, if not cracked, are fairly tight under ordinary drafts. All leaks should be promptly stopped. How and where to look for leaks and the method of stopping them is explained on page 72 of Technical Paper 80.

The engineer or the man directly in charge of the boiler plant should make it a part of his duty to see that all air leakage through the boiler setting is stopped. The responsibility of investigating the leakage can hardly be placed on the fireman's shoulders, because looking for the leakage and stopping it properly requires time which the fireman can not spare if he wishes to do justice to the firing.

If the air leakage into the boiler setting were as visible and as noisy as the leakage of steam from the stuffing boxes and other joints on an engine, it would be promptly stopped. It is safe to say that the loss of heat from air leaks in the boiler setting, as a rule, causes very much larger losses than the leakage of steam about the engine. Part of the time that is frequently spent in needless polishing of brass fittings can be more profitably devoted to stopping leaks in the boiler settings and to other means of reducing boiler-room losses.

LOSSES FROM INCOMPLETE COMBUSTION.

Incomplete combustion is due mainly to two causes—insufficient air supply, and lack of mixing of the air with the combustible rising from the fuel bed.

AIR OVER THE FIRE NECESSARY TO BURN THE FUEL COMPLETELY.

To burn 1 pound of the average coal requires about 14 pounds of air. The air is just as necessary for the combustion as is the coal. When the fuel bed is kept level and 4 to 6 inches thick, only about 7 pounds of air can be supplied through the fuel bed for each pound of coal burned; increasing the rate of air supply merely makes the coal burn faster. The other 7 pounds has to be supplied immediately over the fire. The air supplied through the fuel bed gasifies the coal and the gas must then be burned in the combustion space. This is true no matter how much air we try to force through the fuel bed; if we force through 7 pounds of air, we gasify 1 pound of coal; if we force through 70 pounds, we gasify 10 pounds of coal, and if we force through 700 pounds, 100 pounds of coal is gasified, and so on. In other words, the amount of air supplied through the fuel bed determines only the rate of combustion. The completeness of the combustion is determined by the amount of air that is added and mixed with the combustible gases over the fuel bed. The gases mixed with the air burn in the combustion space and the flames are the visible evidence of this burning of the gases. If there were no gases burning above the fuel bed, there would be no flame.

The additional air needed over the fire should be admitted as close to the fuel bed as possible, in order to make all the space above the fuel bed available for the mixing and the combustion. It should be also supplied in a large number of small streams entering the furnace at high velocity, to facilitate the mixing. This air is usually admitted through openings in the firing door, a rotary damper being provided to control the size of the openings and regulate the amount of air so introduced. Also considerable quantities of air enter the furnace through cracks around the door and leaks in the front and side walls of the furnace. In some plants steam jets are used to aid in mixing the air with the gases. The control of this additional air determines the degree of completeness of combustion.

To admit the additional air through holes in the fire is wholly undesirable, because the quantity of air so introduced can not be controlled. The fireman can not see the size of the holes and can not increase or decrease them at will. The holes are small immediately after firing, when a large supply of air is needed, and burn larger two or three minutes after firing, when a smaller supply is needed. Holes in the fire should be avoided.

CONTROL OF AIR SUPPLY BY GAS ANALYSIS.

The best method of learning what the air supply should be to avoid incomplete combustion and yet not have too large an excess of air is by analyzing the furnace gases with an Orsat apparatus. The fire should be manipulated in such a way and the air admitted in such quantity as to obtain the highest percentage of carbon dioxide in the flue gases without more than 0.3 or 0.4 per cent carbon monoxide. With some furnaces and some coals it may be possible to bring the carbon dioxide content to 14 per cent without getting more than a trace of carbon monoxide, whereas in other furnaces and with other coals it may not be possible to have more than 10 per cent of carbon dioxide without getting an excessive amount of carbon monoxide. The person making the analysis should be sure that the absorbing solution for carbon monoxide is fresh and active.

It is desirable that the engineer make the analysis, direct the fireman what to do, and study the effect of any changes in air adjustment on the composition of the gases. In this way the engineer can determine the best method of burning the coal. He should not become discouraged if he can not get consistent results the first few days he tries the gas-analysis method. He will make mistakes that may tend to discourage him. But he must be patient and make an honest effort to master the task. If he does so, in a few days he will be well repaid for his troubles.

In sampling the gases care should be taken that the apparatus is not leaking and that a representative sample is being obtained. The suggestions given in Bulletin 97, previously referred to, should be closely followed. In taking a "grab" sample, the part of the firing cycle at which the sample is taken should be taken into consideration, because it makes considerable difference whether the sample is taken immediately before or after the firing. Immediately after the firing the carbon dioxide content of the gases will be high and the free oxygen will be low; there may even be an appreciable quantity of carbon monoxide. Two or three minutes after firing the carbon dioxide drops, the oxygen rises, and the monoxide disappears. The analysis will also vary with different coals. Figure 3 shows the amount of carbon dioxide that can be expected during a firing cycle when burning different fuels in hand-fired furnaces. The dots on the curves represent actual readings of carbon dioxide content, taken every 15 to 20 seconds. The firing periods are indicated by the small black rectangles at the bottom of each diagram. The kind of coal and the rate of firing are stated.

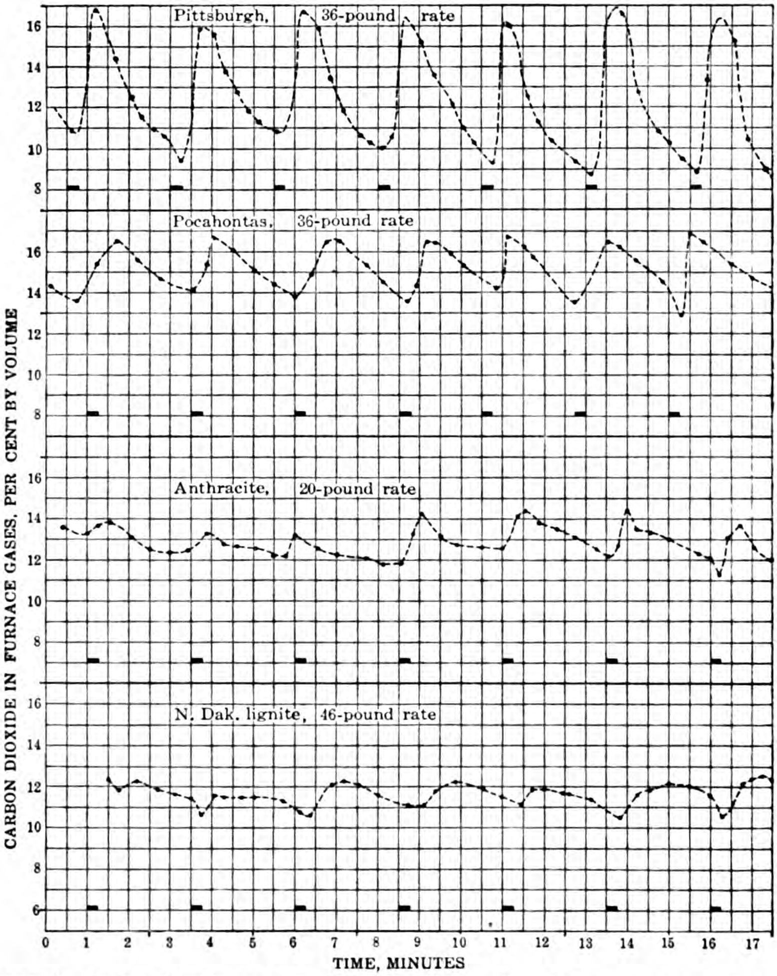

FIGURE 3.—Carbon-dioxide content of furnace gases when different fuels are burned in hand-fired furnaces.

The figure shows that the higher the proportion of volatile matter in the coal the greater is the variation in carbon dioxide during a firing cycle. The variation in volatile matter is responsible for the large variation in carbon dioxide. Immediately after the firing,

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while the coal is being heated, the volatile matter is driven off and all the air entering the furnace above the fuel bed is used in burning the volatile matter. The result is high carbon dioxide. After the volatile matter has been driven off, only the gases from the fixed carbon on the grate need be burned, hence much less air is needed than during the period of distillation. Thus, during the first minute after firing there may not be enough air in the furnace to burn the volatile matter and the gas analysis will show carbon monoxide and very little oxygen. Two or three minutes after firing there will be no carbon monoxide and a large percentage of oxygen, indicating an excess of air. Thus both extremes—the excess of air and insufficient air—are rapidly alternating. For this reason a gas sample taken over a long period may show both an excess of air and a deficiency of air.

Small and frequent firings bring the extremes nearer together, so that higher carbon dioxide can be obtained with no more than traces of carbon monoxide. If the firings are made less than two minutes apart and the two halves of the grate are fired alternately, the firing cycles lap and the composition of the gases is nearly uniform. The engineer should experiment with different length of firing periods and decide for himself which methods give the best results. After the best method of procedure is found the fireman can use it with only occasional checking with the gas analysis.

HIGH FLUE-GAS TEMPERATURE.

The stack losses may be excessively large because the gases may leave the boiler at a high temperature. With the same composition of gases, every 25° F. temperature excess means that, roughly, about 1 per cent of the coal is lost up the stack. The reason that the temperature of the flue gases is high is because the boiler fails to absorb the heat from the gases. This failure to absorb heat may be due to dirty heating surfaces of the boiler, or sometimes to short-circuiting of the path of the gases because baffles are burned out or misplaced. The heating surfaces may be covered on the gas side with a coating of soot and on the water side with a coating of scale. Directions for removing such coating are given in Technical Paper 80, page 71. The usual causes of short-circuit in the gas path are described on pages 73 and 74 of that report.

Continuous measurement of the temperature of flue gases may serve to indicate how clean the boilers are. When temperature measurements are used, the capacity developed by the boiler, as well as the furnace conditions, should be considered, because the capacity and the excess of air supply also affect the temperature of the flue

As a rough approximation, auxiliary power obtained in this way may be said to cost about 4,500 British thermal units per kilowatt-hour of auxiliary power. This figure is obtained as follows: One kilowatt-hour is equivalent to 3,412 British thermal units, and the net cost of obtaining this with the method shown in figure 5 is 3,412 British thermal units plus some boiler losses, steam-pipe losses, and radiation, friction, and windage losses chargeable to 1 kilowatt-hour of auxiliary power. The total is ordinarily not much different from 4,500 British thermal units in fuel per kilowatt-hour of auxiliary power.

It must be noted that this figure holds only for conditions under which the steam exhausted from auxiliaries can be absorbed by the feed water. If a condition arises in which auxiliary exhaust must be discharged to the atmosphere, the auxiliary power must be charged with the heat in its exhaust steam, and a kilowatt-hour generated under these conditions involves an expenditure of 50,000 to 200,000 British thermal units.

It is now possible to demonstrate the fallacy of a common statement to the effect that the economy of the steam engines or turbines used for driving auxiliary apparatus makes no difference in the economy of the plant. In plants of modern proportions the amount of auxiliary power required per kilowatt capacity of main units is such that at light and moderate loads much more auxiliary steam would be made than could be absorbed by the feed water. It therefore follows that if a straight steam-driven auxiliary system is adopted, the greatest thermal efficiency will result when the most efficient engines or turbines are used for driving auxiliaries. Whether the use of such efficient, and therefore costly, auxiliary drives would result in the greatest economic efficiency would depend entirely upon the costs of fuel and capital. Ordinarily, the fuel saving would be such as to balance a very considerable increase in first cost.

"STRAIGHT" ELECTRICAL DRIVE.

The direct opposite of what has been called the unmodified steam method will be designated as the unmodified or "straight" electrical method. In this method all auxiliaries are motor driven and the power is taken from the main units served or from the station bus. Turbine plants of modern design should produce a kilowatt-hour with an expenditure of 19,000 to 25,000 British thermal units in coal. Therefore every kilowatt-hour taken for the driving of auxiliaries represents a thermal cost of the order of 23,000 to 30,000 thermal units, after allowing for the various efficiencies involved.

The unmodified electrical method possesses many advantages, such as reliability, simplicity, flexibility, cleanliness, and such, but it is unquestionably thermally expensive as compared to the other method under conditions that permit total absorption of the exhaust. On the other hand, the thermal cost of auxiliary power generated without reclamation of the heat in the exhaust is two to eight times as large as that characteristic of the "straight" electrical method.

In some of the stations installed a decade or more ago the auxiliary problem was solved by the use of both steam and electrically driven units. This may be designated as the dual system. A sufficient number of steam-driven auxiliaries were operated to give that quantity of exhaust steam which could be absorbed by the station feed, and all of the remaining auxiliary power was obtained electrically with energy taken from the main units. Many systems of this sort are in successful operation.

Obviously, the correct apportionment between the two different methods in the dual system varies with the station load. With high loads and large quantities of feed water the greater part of the auxiliary power is obtained with steam, and with light loads a large part is obtained electrically. Consequently the thermal cost of auxiliary power varies with the load. At high loads this cost tends to approach the 4,500 to 5,000 thermal units characteristic of steam drive with utilization of exhaust, and at light loads it tends to approach a figure nearer 20,000 to 30,000 thermal units.

Following the development of the dual system came many schemes of various sorts for still further reducing the cost of auxiliary power and for increasing operating convenience.

OTHER SYSTEMS FOR DRIVING AUXILIARIES.

One such system drives the auxiliaries electrically with power taken from the main units and heats the feed water with steam drawn from the medium or low pressure stages of the main turbines. This system is capable of many variations but in all of its forms it amounts, thermally, to the generation of auxiliary power with steam up to the ability of the feed water to absorb the exhaust, and the use of electrical energy generated in the main unit for auxiliary power in excess of this quantity. However, as the main units are the source of the steam-generated part of the auxiliary power, the steam drives of the auxiliaries are very economical and a larger proportion of auxiliaries can be driven in this way than could be done if many small steam-driven units were used. Moreover, all advantages of "straight" electrical drive are obtained, and the operation of the system is delightfully simple. The different demands made by the feed water at different loads can be met by merely controlling the steam bled from lower stages of the turbine. By placing the bleeder valves under thermostatic control the operation can be made entirely automatic.

The thermal cost of auxiliary power with this arrangement is similar to that of the dual system, but with normal load curves it should be lower through the greater thermal efficiency of the apparatus used for furnishing the "steam-driven" part of the auxiliary power. Because of the greater thermal efficiency, a smaller number of pounds of "exhaust" steam will be made per unit of auxiliary power generated and a greater part of the total can therefore be generated in this way without exceeding the ability of the feed water to absorb "exhaust" steam.

Another system that has been used extensively is almost the opposite of that last described. The auxiliary apparatus is driven by numerous small steam-operated units. As much as possible of the steam exhausted by these units is absorbed in the feed water and the remainder is fed to the low-pressure stages of the main turbines. By the use of an automatic valve on the auxiliary exhaust the apportionment of exhaust steam can be made automatic in operation; in this respect the system behaves similarly to that last described.

It is obvious that whatever part of the auxiliary power is derived from steam that is later absorbed by the feed water is obtained at the thermal cost characteristic of a "straight" steam system. As the steam drives of the auxiliaries are bound to be of small capacity they are commonly characterized by low thermal efficiency and therefore use a relatively large quantity of steam per kilowatt-hour developed. In this respect the system is less economical than that previously described, because with absorption of exhaust steam by the feed water a smaller part of the total auxiliary demand can be supplied.

A consideration of the thermal cost of that part of the auxiliary power obtained from steam exhausted into the main units is more complicated. In general, it can be assumed that about half of the energy made available by steam expanding from boiler to condenser pressure in modern turbines is developed during the expansion from boiler pressure to atmospheric pressure. The other half is produced by the expansion from atmospheric pressure to the back pressure maintained at the turbine exhaust. Therefore, every pound of auxiliary steam exhausted at about atmospheric pressure into the lower stages of the main turbines may be said to make available at the main generators about the same amount of energy as would be made available by half a pound of steam entering at the high-pressure end of the main turbines and expanding to condenser pressure.

The thermal cost of auxiliary power obtained from steam exhausted into the main units may obviously be obtained by subtracting from the heat supplied the auxiliaries per kilowatt of auxiliary power a credit based on the amount of heat that has been made unnecessary for the supply of the main units. Thus, if the auxiliaries use, say, 50 pounds of high-pressure steam per kilowatt-hour of auxiliary power generated, this steam exhausted into the main units will take the place of 25 pounds of main steam. The net cost of 1 kilowatt-hour of auxiliary power would then be the heat above feed temperature in 25 pounds of high-pressure steam.

With feed at 210° F. and modern pressures and superheats; the quantity of heat thus chargeable per pound would be in the neighborhood of 1,100 British thermal units. In the assumed case the auxiliary power would therefore cost about $25 \times 1,100 = 27,500$ British thermal units per kilowatt-hour. With more efficient auxiliary drives this figure would be lowered and with less efficient auxiliary drives it would be raised.

The values assumed are somewhat lower than would be expected in the average practice, and it is obvious that, in general, this method of obtaining auxiliary power may be expected to be slightly more costly than that last described.

CONCLUSIONS.

A careful consideration of all the methods described thus far warrants these conclusions:

1. The smallest thermal cost for auxiliary power is incurred when generated by steam with complete absorption of the exhaust in the feed water.

2. The greatest possible part of all of the auxiliary energy required can be obtained in this way when the steam drives used with the auxiliaries have the greatest possible thermal efficiency.

3. Auxiliary power in excess of that obtainable with exhaust steam absorption can be procured from the main generators in electrical form at a lower thermal cost than in any other way.

To these conclusions may now be added two commonly known facts:

1. The increasing price of fuel is leading more central stations to the use of economizers.

2. The greatest saving is effected with economizers when the water supplied them is at the lowest permissible temperature. This value is probably somewhere between 120° and 150° F., depending upon the types of economizer used and the care with which it is operated.

At first glance some of the items listed in the two groups seem contradictory when viewed with regard to thermal efficiency. Thus the use of feed water at 140° F., say, must reduce the quantity of auxiliary steam that can be used for feed-water heating and must therefore increase the average cost of auxiliary power. However, when all of the listed items are taken into account they point toward another solution of the auxiliary power problem which has been found both thermally efficient and very practical.

It is obvious that fairly high thermal economy is more readily obtainable with one turbine of moderate size than with a great number of small turbines aggregating the same capacity. It is also obvious that, if the turbine is properly designed, the quantity of steam required by it at any given load will decrease as the back pressure is decreased.

With the system referred to, all, or practically all, of the auxiliaries are electrically driven, but as much as possible of the electric power used is taken from an auxiliary, steam-driven generator of fairly large size. The remainder is taken from the main unit. Steam exhausted by the auxiliary turbogenerator unit is passed into a feed-water heater as in the "straight" steam method, but the feed-water heater is arranged so that it can be operated at a pressure below atmospheric if desired.

The feed-water heater therefore may serve as a condenser so far as the auxiliary turbine is concerned and the water rate of the auxiliary turbine may thus be lowered still further, with reference to the aggregate water rate of a number of small steam units.

This system is thermally the exact counterpart of the dual method previously described. It is, however, thermally superior in that the greater efficiency of the large auxiliary unit makes possible the absorption of the steam made from the generation of a larger part of the total auxiliary power. It is also superior in that a control of the auxiliary steam made is available, for, with any given load, the quantity of steam demanded depends entirely on the back pressure.

These points of superiority can be utilized in two ways. The auxiliary unit may be operated with atmospheric-exhaust pressure, when the advantage gained is merely that of being able to carry a greater part of the total auxiliary load on the steam-driven auxiliary apparatus. Or the auxiliary unit may be operated with low back-pressures, so low as to give feed-water temperatures as low as 140° F.; in this case economizers can be used to full advantage and a greater part of the auxiliary power can be carried on steam-driven machinery than would be permissible with a number of small steam-driven units exhausting at a corresponding temperature.

Thermally, the cost of auxiliary power is approximately 4,500 to 5,000 thermal units for all that power obtained from the auxiliary generator, and all power in excess of this is obtained from the main generator at a thermal cost of 23,000 to 30,000 heat units.

From this hasty survey of the methods of obtaining auxiliary power, and the possible costs of auxiliary power it should be evident that large errors can be made in the original design. It is also possible to make costly errors in operation. To illustrate: Assume that in a certain station, operating at normal day load, the total amount of power used for auxiliaries and for house service of all kinds

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amounts to 10 per cent of that sent out. This is a figure that should not be exceeded but is often equaled. Under these conditions, for every 1,000 kilowatt-hours sent out of the station it is necessary to produce 100 kilowatt-hours for the operation of auxiliaries, station lights, etc.

If it be assumed that the main units are capable of producing a kilowatt-hour for 20,000 thermal units in fuel fired it is possible to show the decidedly weighty influence of the thermal cost of auxiliary power.

It has been shown that auxiliary power may cost anywhere between about 4,500 and 200,000 thermal units, depending on the method used. At 4,500, the auxiliary power would cost about 4,500×100=450,000 thermal units in the assumed case. This would be equal to about 2.25 per cent of 20,000×1,000=20.000,000 thermal units required by the main units. On the other hand, if the auxiliary power costs 200,000 units per kilowatt-hour the total would be 200,000×100=20,000,000, or exactly the same as that required by the main units.

With all auxiliary power taken electrically from efficient main units the cost would probably be at least 23,000 units per kilowatt-hour. This would give a cost in the assumed case equal to 23,000×100=2,300,000, or about 11.5 per cent of that required by the main units for the generation of power leaving the station.

These figures should serve to show the tremendous importance of the proper operation of auxiliary machinery. It does little good to determine the water rates of the main units and operate for a minimum station water rate of these alone, as suggested in the first part of this paper, if the thermal savings effected are equaled or more than equaled by losses through wrong operation of auxiliary systems. Further, the tendency to regard these auxiliary systems as necessary nuisances of no great thermal significance is very apt to lead toward such a state.

In conclusion, as much as possible of the auxiliary power should be obtained in such a way that resultant exhaust steam can be absorbed by the feed water. The remainder of the necessary auxiliary power should be obtained in electrical form from the most efficient units available. The observance of these two rules leads to maximum thermal economy.

The exact method adopted for achieving these desirable results must depend upon the layout and the characteristics of the particular station. No one system is preeminently superior under all conditions. However, it should be noted that the possibilities of a system often can be greatly increased by making comparatively insignificant changes along lines suggested in the preceding discussion.

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Technical Paper 205

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

SAVING COAL IN BOILER PLANTS

BY

HENRY KREISINGER

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SAVING COAL IN BOILER PLANTS.

By Henry Kreisinger.

INTRODUCTION.

This paper, published by the Bureau of Mines in the interest of more efficient utilization of fuels in this country, gives suggestions as to what can be done in the boiler room to save coal. It covers the field between two other Bureau of Mines publications, Technical Paper 80, "Hand Firing Soft Coal Under Power-Plant Boilers," and Bulletin 97, "Sampling and Analysis of Flue Gases." It is written for the fireman, the engineer, and the owner of the small or medium size plant, which is, as a rule, hand fired.

The large plants usually have efficient and modern equipment, are mechanically fired, and are operated under the direction of technically trained and experienced men who hardly need such general suggestions as are given in a paper of this character. The small and the medium size plants, of which there are a very large number, have less efficient equipment, and, in addition, their size makes it inadvisable to retain a highly trained boiler-room operator. For these reasons fuel losses are likely to be higher in the smaller plants, and there such suggestions as are made in this paper will prove of greatest benefit. In these plants the hope of decreasing the losses lies entirely in the fireman, the engineer, and the owner or manager. These three men must closely cooperate if the desired results are to be obtained. The fireman and the engineer should give good will and steady endeavor; the owner or manager of the plant should encourage the firemen and the engineer to save coal, and should show appreciation of their efforts.

The fireman should keep in mind that his duty is to make steam and not merely to burn coal. He must be willing to learn and be patient with his progress, whether studying printed suggestions or trying such suggestions in practice. He should not be discouraged if he has difficulty in understanding them or if his progress is slow. He must make honest effort. He should bear in mind that there is no royal road to knowledge and skill.

The engineer should cooperate with the fireman full-heartedly; complete cooperation is absolutely necessary if their efforts are to be successful. Usually, the engineer will decide what method should be tried. He should endeavor to give each method an honest trial and study the results impartially before making conclusions. In nearly every plant the engineer can find ways of saving coal, if he seeks for them, and it is his duty to find the best methods and see to it that they are put into practice. He should take pride in any real success that has been attained through his effort and perseverance. He should devote part of his time to reading and studying literature on the economical operation of power plants, particularly any articles on saving coal. It is true that all the suggestions made in such articles will not apply to the plant where he is employed, but doubtless many of them can be readily adopted. Above all, and for his own sake, he should avoid being indifferent.

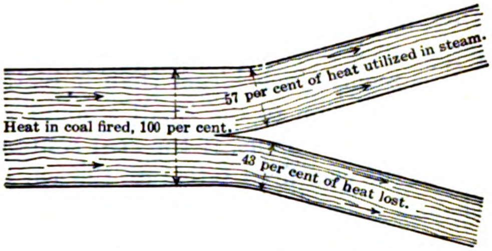
The owner, or manager, of the plant should encourage the fireman and the engineer in their efforts to save coal by providing them with the necessary tools and instruments, and should show his appreciation of any improvement in the efficiency of the plant by a suitable reward, preferably in wages or bonus payments. Such appreciation is important and necessary if the good work in the boiler room and engine room is to be continued.

These principles and most of the suggestions made in this paper apply equally to mechanical stoker plants.

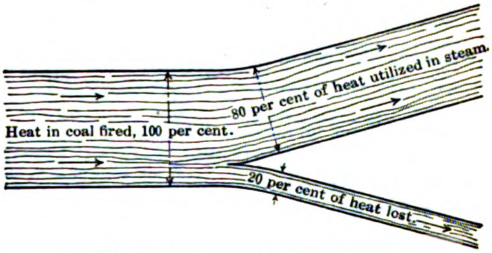
WHAT CAN BE DONE IN SAVING COAL.

In the average steam plant, 57 per cent of the heat in the coal burned under the boilers is utilized in making steam and 43 per cent is lost—that is, of 100 tons of coal fired under the boiler, 57 tons is actually utilized in making steam, and 43 tons is not used, from various causes. Some of the large plants get results considerably better than this, but many of the small plants get poorer results. Records of the best performances show that about 80 per cent of the coal burned was actually utilized in making steam, and, although such high results can not be obtained with the existing apparatus or equipment in some plants, a requirement of 65 to 70 per cent is justifiable. The diagrams in figure 1 show what is being done and what is possible. Raising the average efficiency from 57 to 67 per cent means the saving of about 15 tons of coal out of every 100 tons. At present about 300,000,000 tons of coal annually are necessary to supply all the steam plants in this country, whereas with proper care taken in operating these plants only about 255,000,000 tons would be needed, making a saving of about 45,000,000 tons.

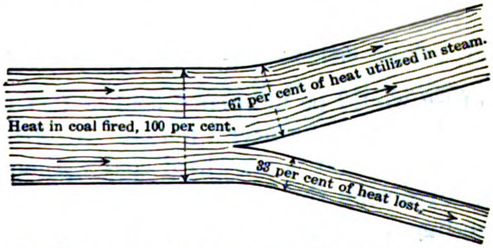
How are these steam plants to increase their average efficiency from 57 to 67 per cent? The method is simple, and easy to understand, although to many it may seem slow in bringing results and perhaps tedious to follow. It is the application of the essential principles already mentioned—namely, good will and steady honest effort on the part of the fireman and the engineer; and encouragement and appreciation on the part of the owner or manager of the plant. Only these means will bring the desired results. There is no miraculous powder that when dissolved in water and sprinkled over coal will make it give up more heat and produce more steam. All powders sold under such pretenses are frauds. Also, there are no patented devices that when attached to the boiler will automatically make large savings without the effort of the fireman or the engineer. Many patented fuel-saving devices have elements of merit, but they must have careful, intelligent attention to do good work. It has been said that there is no royal road to knowledge; if a man wants to understand, he has to study, learn, and work. It can be said equally well that there is no royal road to saving coal; the engineer and the fireman must study, learn, and work, each in his own way. Careful, sincere endeavor by the fireman and the engineer and the hearty cooperation of the owner are absolutely essential to success in any campaign for saving fuel. These requirements must be furnished by the men of the plant; they can not be bought on the market. On the following pages are given suggestions as to how these requirements should be applied.


57 per cent of heat utilized in steam.
Heat in coal fired, 100 per cent.
43 per cent of heat lost.

A. The average boiler plant does like this.


80 per cent of heat utilized in steam.
Heat in coal fired, 100 per cent.
20 per cent of heat lost.

B. The best plants are doing like this.


67 per cent of heat utilized in steam.
Heat in coal fired, 100 per cent.
33 per cent of heat lost.

C. The average plant can and should do like this.

FIGURE 1.—Diagrams showing possible improvement in efficiency at average boiler plants.

HOW HEAT IS LOST AND COAL WASTED.

Figure 1 shows the amount of heat lost in the boiler plant, but does not show how it is lost, and what can be done to reduce the loss. The way the heat is lost is indicated, in a general way, in figure 2. That is, in the average plant, about 4 per cent of the 43 per cent lost goes down with the ashes, 4 per cent is lost by radiation, and 35 per cent goes up the stack. The heat loss up the stack is the greatest in the boiler room, and the efforts of the fireman and the engineer should be centered on reducing it.

THE ASH-PIT LOSS.

In the hand-fired plant the ash-pit loss is usually small because unburned combustible is easily detected in the refuse. If the ash contains much combustible, it can be readily seen without the aid of special instruments; also the loss from partly burned coal or cinder always seems much larger than it really is, because the fireman sees it in proportion to the small amount of ash formed rather than to the coal fired. Thus, if the coal contains 10 per cent ash, and 5 per cent of the coal fired falls into the ash pit, the refuse will be 10 parts ash and 5 parts unburned coal. In other words, one-third of the refuse would be unburned coal, a fact that could not escape the fireman's or the engineer's notice. No fireman would keep on wheeling out refuse that is one-third coal without trying to improve his firing or attracting the engineer's attention to it, and even if he should be negligent enough to do so, he would very likely be reprimanded by the engineer or the owner, as soon as they noticed it. On the other hand, if the loss is small the fireman should receive some pleasant word of appreciation to encourage him in his effort. Deserved recognition will awaken interest in his work and pride in his skill. Suggestions for improvement are much more effective when they are made in a way that appeals to a man's pride.

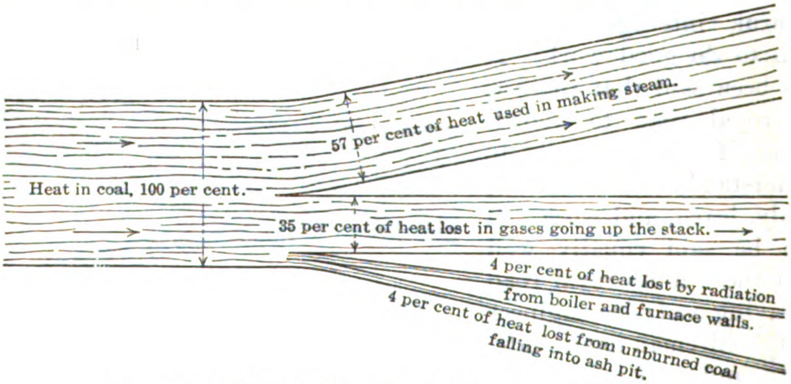

57 per cent of heat used in making steam.
Heat in coal, 100 per cent.
35 per cent of heat lost in gases going up the stack.
4 per cent of heat lost by radiation from boiler and furnace walls.
4 per cent of heat lost from unburned coal falling into ash pit.

FIGURE 2.—Where the heat goes in the average boiler plant.

CAUSES OF HIGH ASH LOSS, AND REMEDY.

The most common causes of a high ash loss are improper cleaning of fires, bare spots, and useless poking of fires. If the cleaning is not properly done, a large quantity of combustible is pulled out of

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the furnace with the clinker and ashes. After cleaning, if there is not enough burning coal left in the furnace to cover the grate completely, and fine coal is fired, some of it sifts into the ash pit. Therefore, when fires are cleaned care should be taken that there is enough burning coal on the grate to start a good fire after the cleaning is completed. Effort should also be made to run the fires in such a way that few cleanings are necessary, and that these are done when there is little or no load on the boiler. Fires can be run longer without cleaning if they are built gradually with small and frequent firings. Heavy firings immediately after cleaning have a tendency to start troublesome clinker. In industrial plants a day's run should be started with a thoroughly clean fire, built gradually to full steaming capacity. Perhaps in no other kind of work is a good start of such advantage as in running fires. A more thorough discussion of methods of cleaning fires is given on page 31 of Bureau of Mines Technical Paper 80, "Hand Firing Soft Coal Under Power-Plant Boilers."

Frequent poking of fires may cause an excessive loss from coal falling into the ash pit. Also the poking increases the tendency of the coal to clinker, thereby making necessary more frequent cleaning.

In some fires high ash loss is caused by bare spots on the grate. The firings may be so far apart that the fuel bed burns through in places. When the fireman attempts to cover these bare places the fine coal sifts into the ash pit. The remedies are to fire frequently and place coal on the thin spots before they burn through and form holes.

THE RADIATION LOSS.

The radiation from the boiler is usually small if the boiler has been properly set, and little can be done to reduce it. Of course, all steam and hot-water pipes should be covered with insulating material.

THE LOSS UP THE STACK.

In the average boiler plant, 35 per cent of the heat in the coal burned under the boilers is lost with the stack gases. That is, out of every 100 tons of coal burned under the boilers, the heat of 35 tons literally goes up the stack. It is this loss that can be greatly reduced and every effort should be made to do so.

The stack loss is so large because its magnitude can not be readily detected. Nobody can tell how much heat is going up the stack simply by looking at the stack. The density of the visible smoke is no indication of the amount of heat being lost. The magnitude of the loss can be found only by the use of special instruments and carefully kept records.

By far the largest part of the stack loss is heat held by the gases because of the high temperature at which they leave the boiler. This part of the loss is unduly large when too much air enters the furnace and the boiler setting; it can be greatly reduced by decreasing the excess of air and by lowering the temperature of the gases leaving the boiler. To burn 1 pound of coal requires about 14 pounds of air. This air enters the furnace at atmospheric temperature and leaves the boiler at a temperature about 500° F. higher. It carries with it all the heat it absorbed in being heated through this temperature range of 500 degrees. Each pound of air absorbs approximately one-fourth of a heat unit (B. t. u.) for each degree of temperature rise. Therefore, each pound of air, in being heated 500 degrees, absorbs $\frac{500}{4}=125$ heat units. Fourteen pounds of air absorbs $14\times125=1{,}750$ heat units. If, instead of 14 pounds of air being admitted for each pound of coal fired, 28 pounds is admitted into the furnace, the heat carried away by this weight of air will be $28\times125=3{,}500$ heat units, or twice as much as in the furnace using 14 pounds. Again, if the gases should leave the boiler at a temperature 1,000 degrees higher than atmospheric they would carry away twice as much heat as gases heated to only 500 degrees, and one pound of gas would carry away $\frac{1000}{4}=250$ heat units. Therefore, the amount of heat carried away by the flue gases depends directly upon the weight of air entering the furnace and the temperature rise. Air entering the furnace in excess of about 14 pounds to a pound of coal burned is not necessary to good combustion, and the heat it carries away when leaving the boiler is wasted.

The stack loss also includes the heat units in the unburned combustible gas and in the visible smoke. This part of the loss is due to the lack of enough air at the right time and place to burn the gases completely. Thus one part of the stack loss is due to excessive supply of air, and the other part to insufficient supply of air. Hence, there is always the possibility that by reducing one part of the loss we may increase the other part. However, in the average plant the loss from excess air supplied to the furnace is far larger than the loss from incomplete combustion, and the sum of the two can be greatly reduced by decreasing the excess of air. In many plants both parts of the stack loss can be reduced by more careful firing.

METHODS OF DETERMINING STACK LOSSES.

ORSAT APPARATUS.

The most direct method of determining the stack losses is by chemical analysis of the flue gases, and measurement of their temperature. A fairly complete analysis of the gases can be made with an Orsat apparatus. From the results of such an analysis, and the temperature, the magnitude of the loss due to large excess of air and also the loss due to incomplete combustion can be found. In large plants it will pay to hire a trained man to make analyses of the gases and to direct the firemen. In the smaller plants the engineer should become thoroughly skilled with the Orsat apparatus, and use it. By using the Orsat apparatus intelligently he can learn more about proper methods of firing and operating the boilers than in any other way, and he can earn his salary better than by performing less important duties, such as he is often called on to do.

In many plants of 1,000 to 2,000 horsepower capacity, the engineer is required to be a pipefitter, a millwright, a blacksmith, a machinist, and many other varied and often trivial duties are placed on his shoulders. These secondary duties frequently keep him so busy that he has scarcely any time to find out how the plant is running and how much fuel it uses. Making the plant develop the needed power with the least amount of coal should be the engineer's chief and, perhaps, only duty, and as a general proposition, it will pay the owner to make it so. When a plant uses $50 to $100 worth of coal a day, efforts to save 10 per cent of it will pay. The days of low-priced coal are gone, probably never to return.

Many engine operators believe that the Orsat appartus is too delicate and the gas analysis is too difficult for anyone but a skilled chemist, and for that reason they are diffident about trying it. As a matter of fact the Orsat is a much simpler instrument and much easier to manipulate than a steam-engine indicator, which most engineers know how to use. With careful effort an engineer ought to be able to learn to use an Orsat in one or two days. An Orsat apparatus is much cheaper than an indicator outfit, costing only about one-third as much, and as far as saving coal is concerned is much more useful than the indicator.

For studying the merits of different methods of firing, "grab" samples of the furnace gases taken at different intervals of time after firing will be found useful. For the determination of the chimney losses or to test the skill of different firemen, the "time" sample, collected over long periods, should be used.

SAMPLING AND COLLECTING FLUE GASES.

For the ordinary work in the boiler room the simple open-end gas sampler is the most convenient to use, and when carefully placed gives good results. The sampler can be made of standard ¼ or ⅛ inch iron pipe, placed with the free open end in the center of the gas stream. If the sampler is placed in the uptake, the opening of the sampler should be so placed that the sample will be affected as little as possible by the damper changes. Figures 3 and 4 of Bulletin 97, Bureau of Mines, "Sampling and Analysis of Flue Gases," show a good position for the sampler in the uptake. Figure 12, on page 21 of the same bulletin, shows the position of the sampler in the third pass of a cross-flow, water-tube boiler, the sampler being inserted through a cleaning hole in the side of the setting. In the parallel-flow type of boiler the sampler can be inserted through one of the hollow staybolts.

The gas sample can be drawn into a special collecting bottle or directly into the Orsat apparatus. For a detailed study of what happens in the furnace the sample should be taken directly into the Orsat, and as many samples analyzed as possible. When this is done the sampler should be of the smallest pipe available and the connections should be so short that the sampler and the connection hold only a small volume of gas. Before a sample is taken for analysis, the air or gas in the sampler should be drawn out. In studying the results of a gas analysis due allowance should be made for leakage of air into the setting between the furnace and the place of sampling.

Complete information on the sampling, collecting, and analyzing of flue gases is given on pages 7 to 34 of Bulletin 97. A method of calculating the stack losses from the analysis is given on pages 35 to 39 of that bulletin.

AUTOMATIC CARBON-DIOXIDE RECORDERS.

For determining the amount of excess air entering the furnace an automatic carbon-dioxide recorder can be used. The carbon-dioxide recorder costs considerably more than an Orsat gas-sampling apparatus and does not indicate the incompleteness of combustion. The carbon-dioxide indication should be checked from time to time with an Orsat apparatus. The recorders have the advantage that, after proper adjustment, they run automatically with little attention from the operator and make a continuous record from which the loss due to excess of air can be approximately calculated. A description of the various makes and directions for operating them are given in Bulletin 91, Bureau of Mines, "Instruments for Recording Carbon Dioxide in Flue Gases."

SIGNIFICANCE OF FLUE-GAS ANALYSIS.

Large excess of air is indicated by low carbon-dioxide content and high-oxygen content. Incomplete combustion is indicated by carbon monoxide. An average of 10 to 12 per cent of carbon dioxide in the flue gases can be considered as good performance, provided the percentage of carbon monoxide is small. Some boiler furnaces can be run with the gases containing as high as 14 per cent carbon dioxide without carbon monoxide appearing, whereas in other furnaces the gases may show a considerable amount of carbon monoxide even with 10 per cent of carbon dioxide, particularly with large firings. As a general rule, the monoxide content in the flue gases should not be allowed to reach one-half of 1 per cent. It should be remembered that carbon monoxide is only one of the combustible gases; there may be hydrogen (H_2) and in small furnaces even a small amount of methane (CH_4). The actual total loss from incomplete combustion may be twice as large as that indicated by the percentage of carbon monoxide. Methods of calculating this loss are given in Bulletin 97, on pages 38 to 43.

CAUSES OF LARGE EXCESS OF AIR AND REMEDY.

The causes of large excess of air are: Holes in the fire, frequent raking or slicing of the fire, too large openings in the dampers of the firing door, badly warped fire doors that can not be shut tightly, leaky settings, and firing doors kept open too long.

HOLES IN THE FIRE.

Holes in the fire are by far the most common cause of large excess of air in the flue gases and large losses of heat up the chimney. Such holes are entirely within the control of the fireman; therefore it is evidently his duty to prevent them. The forming of holes can be avoided by firing frequently and placing the coal on the thin spots of the fuel bed. The more frequent the firing the less chance there is for holes to form. Complete directions for firing are given in the first 20 pages of Technical Paper 80, Bureau of Mines, "Hand Firing Soft Coal Under Power-Plant Boilers."

It often happens that if the fireman keeps the fire level by small and frequent firings, the steam pressure rises to the blowing-off point. The rise of the steam pressure is a result of two causes—more coal is burned than is needed, and there is no cooling effect from air entering through holes in the fuel bed. Then the fireman, in order to avoid wasting of steam, usually fires less often and thus lets the fire burn out in spots. As soon as he discovers that the fire is burning through, he should take steps to keep the fire free from holes. If he must put on more coal than is necessary to keep the pressure up, he should reduce the draft by partly closing the uptake damper, so that the coal will burn more slowly. In other words, the amount of coal fired should be adjusted to the demand for steam, and the volume of air flowing through the fuel bed should be adjusted by the draft damper to the amount of coal that must be burned.

The fireman must grasp this principle and understand it. For every pound of coal burned on the grate 7 pounds of air must be made to flow through the burning bed of coal, and through it only. Most of the air that flows into the furnace through a hole in the fire does not aid in burning the coal surrounding the hole. The stream of air merely absorbs a large quantity of heat and carries it out through the stack. The amount of air flowing up through a level bed of burning coal depends on the draft; the stronger the draft the more air flows through the fire and the faster the coal is burned. Also, the weaker the draft the less air flows through the fuel bed and the slower the coal burns. Each 7 pounds of air burns or gasifies one pound of coal in the fuel bed; if the air is supplied at a faster rate than 7 pounds to a pound of coal, the fire will burn out, and holes are formed. If, on the other hand, the air is supplied more slowly than the coal is fired, the coal will accumulate and pile up into a thick bed.

PROPER REGULATION OF DRAFT ESSENTIAL.

Therefore, proper regulation of the draft is very important for efficient burning of coal. In order to enable the fireman to regulate the draft properly, the uptake damper connection should be made in such a way that he can handle this damper from the floor in front of the furnace, and handle it easily and often. Also, the furnace should have a draft gage, so that he can adjust the damper to obtain the draft desired. The engineer should see that the boilers have the proper damper connections within convenient control of the fireman. Two kinds of damper connections are shown on pages 22 and 23 of Technical Paper 80, "Hand Firing Soft Coal under Power-plant Boilers." The owner of the plant should encourage the engineer and the fireman in their efforts to burn his coal efficiently, by providing draft gages and the necessary materials needed for connections.

The draft should be changed gradually; the damper should not alternately be nearly closed and then fully opened. In burning coal there is nothing more wasteful than sudden changes in draft.

THE DRAFT GAGE.

The draft gage gives the fireman valuable information as to the condition of the fuel bed. If the indication is too high he may be sure that the fuel bed is too thick or that there is a large accumulation of clinkers. If the indication is too low he should suspect there are thin spots or holes in the fire, and cover them.

The draft gage is as necessary for efficient operation of boilers as the pressure gage or the water gage. If the steam pressure is too high the safety valve blows off and lets the fireman know that he is burning too much coal. On the other hand, if there are holes in the fire, the air entering the furnace through the holes may carry away more heat through the stack than would be blown off through the safety valve without exciting the fireman's suspicion. If there is a draft gage connected to the furnace, the low indication on the gage would warn the fireman.

KEEPING THE FUEL BED LEVEL.

Frequent raking and slicing of the fire causes large losses of heat up the stack, because whenever the fireman rakes or slices the fires a large excess of air enters the furnace through the open fire doors. The firing should be done in such a way that raking and slicing becomes unnecessary. The fire should be kept level by firing small charges at short intervals and placing the coal on the thin spots. Small and frequent firings largely prevent the forming of a crust and of high places, which would have to be broken and leveled with a rake. Slicing can be reduced to a minimum by keeping the fire rather thin—5 to 6 inches gives good results in the average hand-fired plant.

A thick fire and accumulations of clinker on the grate may cause large stack losses because of the large excess of air. Such conditions in the fuel bed tend to increase the draft over the fire, thereby causing entirely too much air to flow into the furnace through the openings in and around the firing doors. The high draft in the furnace also increases the leakage of air into the setting. It is well to add that thick fires are the most common cause of troublesome clinker. For a discussion of thick fires and the causes and remedies for clinker, the reader is referred to Technical Paper 80, pages 29 and 38.

It is plainly a part of the duty of a good fireman to avoid the losses caused by frequent poking of fires, thick fuel beds, and accumulations of clinker, and it is up to him to "do his bit."

LEAKAGE OF AIR INTO THE SETTING.

Leakage of air into boiler settings is probably the next largest cause of excessive chimney losses. In the average plant about one-third of the gases in the breeching is air that has leaked into the setting; in many small plants the leakage is even higher; and even in a well-kept plant it runs one-tenth to two-tenths. Most of the leakage is through cracks in the walls, around and through cleaning and access doors, and through joints between the metallic parts of the boiler and the masonry. The walls themselves, if not cracked, are fairly tight under ordinary drafts. All leaks should be promptly stopped. How and where to look for leaks and the method of stopping them is explained on page 72 of Technical Paper 80.

The engineer or the man directly in charge of the boiler plant should make it a part of his duty to see that all air leakage through the boiler setting is stopped. The responsibility of investigating the leakage can hardly be placed on the fireman's shoulders, because looking for the leakage and stopping it properly requires time which the fireman can not spare if he wishes to do justice to the firing.

If the air leakage into the boiler setting were as visible and as noisy as the leakage of steam from the stuffing boxes and other joints on an engine, it would be promptly stopped. It is safe to say that the loss of heat from air leaks in the boiler setting, as a rule, causes very much larger losses than the leakage of steam about the engine. Part of the time that is frequently spent in needless polishing of brass fittings can be more profitably devoted to stopping leaks in the boiler settings and to other means of reducing boiler-room losses.

LOSSES FROM INCOMPLETE COMBUSTION.

Incomplete combustion is due mainly to two causes—insufficient air supply, and lack of mixing of the air with the combustible rising from the fuel bed.

AIR OVER THE FIRE NECESSARY TO BURN THE FUEL COMPLETELY.

To burn 1 pound of the average coal requires about 14 pounds of air. The air is just as necessary for the combustion as is the coal. When the fuel bed is kept level and 4 to 6 inches thick, only about 7 pounds of air can be supplied through the fuel bed for each pound of coal burned; increasing the rate of air supply merely makes the coal burn faster. The other 7 pounds has to be supplied immediately over the fire. The air supplied through the fuel bed gasifies the coal and the gas must then be burned in the combustion space. This is true no matter how much air we try to force through the fuel bed; if we force through 7 pounds of air, we gasify 1 pound of coal; if we force through 70 pounds, we gasify 10 pounds of coal, and if we force through 700 pounds, 100 pounds of coal is gasified, and so on. In other words, the amount of air supplied through the fuel bed determines only the rate of combustion. The completeness of the combustion is determined by the amount of air that is added and mixed with the combustible gases over the fuel bed. The gases mixed with the air burn in the combustion space and the flames are the visible evidence of this burning of the gases. If there were no gases burning above the fuel bed, there would be no flame.

The additional air needed over the fire should be admitted as close to the fuel bed as possible, in order to make all the space above the fuel bed available for the mixing and the combustion. It should be also supplied in a large number of small streams entering the furnace at high velocity, to facilitate the mixing. This air is usually admitted through openings in the firing door, a rotary damper being provided to control the size of the openings and regulate the amount of air so introduced. Also considerable quantities of air enter the furnace through cracks around the door and leaks in the front and side walls of the furnace. In some plants steam jets are used to aid in mixing the air with the gases. The control of this additional air determines the degree of completeness of combustion.

To admit the additional air through holes in the fire is wholly undesirable, because the quantity of air so introduced can not be controlled. The fireman can not see the size of the holes and can not increase or decrease them at will. The holes are small immediately after firing, when a large supply of air is needed, and burn larger two or three minutes after firing, when a smaller supply is needed. Holes in the fire should be avoided.

CONTROL OF AIR SUPPLY BY GAS ANALYSIS.

The best method of learning what the air supply should be to avoid incomplete combustion and yet not have too large an excess of air is by analyzing the furnace gases with an Orsat apparatus. The fire should be manipulated in such a way and the air admitted in such quantity as to obtain the highest percentage of carbon dioxide in the flue gases without more than 0.3 or 0.4 per cent carbon monoxide. With some furnaces and some coals it may be possible to bring the carbon dioxide content to 14 per cent without getting more than a trace of carbon monoxide, whereas in other furnaces and with other coals it may not be possible to have more than 10 per cent of carbon dioxide without getting an excessive amount of carbon monoxide. The person making the analysis should be sure that the absorbing solution for carbon monoxide is fresh and active.

It is desirable that the engineer make the analysis, direct the fireman what to do, and study the effect of any changes in air adjustment on the composition of the gases. In this way the engineer can determine the best method of burning the coal. He should not become discouraged if he can not get consistent results the first few days he tries the gas-analysis method. He will make mistakes that may tend to discourage him. But he must be patient and make an honest effort to master the task. If he does so, in a few days he will be well repaid for his troubles.

In sampling the gases care should be taken that the apparatus is not leaking and that a representative sample is being obtained. The suggestions given in Bulletin 97, previously referred to, should be closely followed. In taking a "grab" sample, the part of the firing cycle at which the sample is taken should be taken into consideration, because it makes considerable difference whether the sample is taken immediately before or after the firing. Immediately after the firing the carbon dioxide content of the gases will be high and the free oxygen will be low; there may even be an appreciable quantity of carbon monoxide. Two or three minutes after firing the carbon dioxide drops, the oxygen rises, and the monoxide disappears. The analysis will also vary with different coals. Figure 3 shows the amount of carbon dioxide that can be expected during a firing cycle when burning different fuels in hand-fired furnaces. The dots on the curves represent actual readings of carbon dioxide content, taken every 15 to 20 seconds. The firing periods are indicated by the small black rectangles at the bottom of each diagram. The kind of coal and the rate of firing are stated.

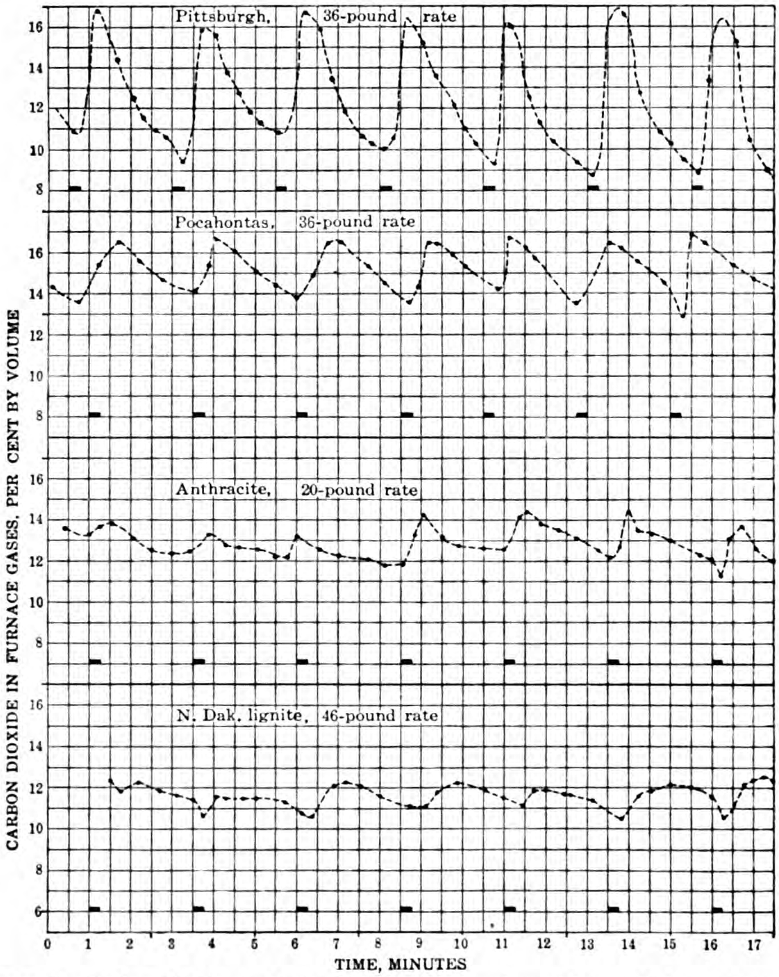

FIGURE 3.—Carbon-dioxide content of furnace gases when different fuels are burned in hand-fired furnaces.

The figure shows that the higher the proportion of volatile matter in the coal the greater is the variation in carbon dioxide during a firing cycle. The variation in volatile matter is responsible for the large variation in carbon dioxide. Immediately after the firing, while the coal is being heated, the volatile matter is driven off and all the air entering the furnace above the fuel bed is used in burning the volatile matter. The result is high carbon dioxide. After the volatile matter has been driven off, only the gases from the fixed carbon on the grate need be burned, hence much less air is needed than during the period of distillation. Thus, during the first minute after firing there may not be enough air in the furnace to burn the volatile matter and the gas analysis will show carbon monoxide and very little oxygen. Two or three minutes after firing there will be no carbon monoxide and a large percentage of oxygen, indicating an excess of air. Thus both extremes—the excess of air and insufficient air—are rapidly alternating. For this reason a gas sample taken over a long period may show both an excess of air and a deficiency of air.

Small and frequent firings bring the extremes nearer together, so that higher carbon dioxide can be obtained with no more than traces of carbon monoxide. If the firings are made less than two minutes apart and the two halves of the grate are fired alternately, the firing cycles lap and the composition of the gases is nearly uniform. The engineer should experiment with different length of firing periods and decide for himself which methods give the best results. After the best method of procedure is found the fireman can use it with only occasional checking with the gas analysis.

HIGH FLUE-GAS TEMPERATURE.

The stack losses may be excessively large because the gases may leave the boiler at a high temperature. With the same composition of gases, every 25° F. temperature excess means that, roughly, about 1 per cent of the coal is lost up the stack. The reason that the temperature of the flue gases is high is because the boiler fails to absorb the heat from the gases. This failure to absorb heat may be due to dirty heating surfaces of the boiler, or sometimes to short-circuiting of the path of the gases because baffles are burned out or misplaced. The heating surfaces may be covered on the gas side with a coating of soot and on the water side with a coating of scale. Directions for removing such coating are given in Technical Paper 80, page 71. The usual causes of short-circuit in the gas path are described on pages 73 and 74 of that report.

Continuous measurement of the temperature of flue gases may serve to indicate how clean the boilers are. When temperature measurements are used, the capacity developed by the boiler, as well as the furnace conditions, should be considered, because the capacity and the excess of air supply also affect the temperature of the flue gases. A method of measuring the temperature of flue gases is given in Bulletin 145, "Measuring the Temperature of Gases in Boiler Settings."

ACCURATE AND RELIABLE RECORDS AS MEANS OF REDUCING LOSSES.

Suggestions as to what records should be kept in the power plant are given on page 67 of Technical Paper 80. There may be other records, not mentioned in that paper, that will prove helpful in finding and correcting wastes. All periodicals on power-plant operation from time to time publish articles on methods and systems for making power-plant records applicable to certain plants. The engineer should study the various methods of making records, and adopt the one best suited to his plant. Whatever method of making records is chosen, it should furnish means to obtain the exact input and the exact output of the plant. The input is always the weight of the fuel burned. The ideal figure for the output of the plant would be the weight of steam made. The weight of water fed the boiler may be a near approach to this. In some plants records for the output are difficult to make; it is necessary to go farther away from the boiler to obtain the record. Of course, the farther from the boiler one goes, the more factors enter into the records and the less reliable is the report. The output may be taken as the horsepower developed by the engine, the electrical energy of a generator, the weight of the ice made in an ice plant, or, if it is an industrial plant with well standardized product, it may be the weight of the manufactured product, such as cotton cloth.

Making accurate records is only a part of the problem. In order to get the full value of these records they must be closely studied and used as a guide for any changes in the methods of operation. They should also be made the basis of any premium or bonus which may be awarded to the deserving plant employees who increase the efficiency in the use of coal.

The best man for studying the records is the engineer, because by doing it he learns many things about the operation of the plant that he could not learn in any other way. He accumulates quantitative knowledge; in other words, he learns the operation of his plant in exact figures, which, after all, is the real knowledge.

AWARDING THE REWARDS.

The awarding of just rewards to the fireman and engineer for successful efforts in saving coal is absolutely necessary if their efforts are to continue. They must feel that they get fair treatment.

The greatest obstacle to awarding deserved rewards is the lack of a fair and easily obtained basis for adjudging such rewards. The

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fairest basis for the fireman would undoubtedly be the pounds of water evaporated per pound of coal burned. Unfortunately, many plants have no means for keeping records to obtain such a basis. Every effort should be made to get such records by measuring the water fed into the boilers or the steam passing out through the steam header. A certain number of pounds of water evaporated for each pound of coal fired could be adopted for a standard, and every time higher evaporation than the standard is obtained the fireman and the engineer could receive a reward proportional to the increase of evaporation. Corrections would have to be made if the demand for steam was varying from the standard capacity; also, the quality of the coal would have to be taken into consideration.

The engineer should study the conditions under which the plant is operating and devise some basis of reward that would be fair to the owner and to the plant employees.

PUBLICATIONS ON THE UTILIZATION OF COAL AND LIGNITE.

A limited supply of the following publications of the Bureau of Mines has been printed and is available for free distribution until the edition is exhausted. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 5. Washing and coking tests of coal at the fuel-testing plant, Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp., 1 fig.

BULLETIN 6. Coals available for the manufacture of illuminating gas, by A. H. White and Perry Barker, compiled and revised by H. M. Wilson. 1911. 77 pp., 4 pls., 12 figs.

BULLETIN 55. The commercial trend of the producer-gas power plant, by R. H. Fernald. 1913. 93 pp., 1 pl., 4 figs.

BULLETIN 58. Fuel-briquetting investigations, July, 1904, to July, 1912, by C. A. Wright. 1913. 277 pp., 21 pls., 3 figs.

BULLETIN 76. United States coals available for export trade, by Van. H. Manning. 1914. 15 pp., 1 pl.

BULLETIN 85. Analyses of mine and car samples of coal collected in the fiscal years 1911 to 1913, by A. C. Fieldner, H. I. Smith, A. H. Fay, and Samuel Sanford. 1914. 444 pp., 2 figs.

BULLETIN 89. Economic methods of utilizing Western lignites, by E. J. Babcock. 1915. 74 pp., 5 pls., 5 figs.

BULLETIN 119. Analyses of coals purchased by the Government during the fiscal years 1908–1915, by G. S. Pope. 1916. 118 pp.

BULLETIN 135. Combustion of coal and design of furnaces, by Henry Kreisinger, C. E. Augustine, and F. K. Ovitz. 1917. 144 pp., 1 pl., 45 figs.

BULLETIN 136. Deterioration in the heating value of coal during storage, by H. C. Porter and F. K. Ovitz. 1917. 38 pp., 7. pls.

BULLETIN 138. Coking of Illinios coals, by F. K. Ovitz. 1917. 71 pp., 11 pls., 1 fig.

Bulletin 145. Measuring the temperature of gases in boiler settings, by Henry Kreisinger and J. F. Barkley. 1918. 72 pp., 31 figs.

TECHNICAL PAPER 16. Deterioration and spontaneous heating of coal in storage, a preliminary report, by H. C. Porter and F. K. Ovitz. 1912. 14 pp.

TECHNICAL PAPER 34. Experiments with furnaces for a hand-fired return tubular boiler, by S. B. Flagg, G. C. Cook, and F. E. Woodman. 1914. 32 pp., 1 pl, 4 figs.

TECHNICAL PAPER 50. Metallurgical coke, by A. W. Belden. 1913. 48 pp., 1 pl., 23 figs.

TECHNICAL PAPER 76. Notes on the sampling and analysis of coal, by A. C. Fieldner. 1914. 59 pp., 6 figs.

TECHNICAL PAPER 80. Hand firing soft coal under power-plant boilers, by Henry Kreisinger. 1915. 83 pp., 32 figs.

TECHNICAL PAPER 97. Saving fuel in heating a house, by L. P. Breckenridge and S. B. Flagg. 1915. 35 pp., 3 figs.

TECHNICAL PAPER 98. Effect of low-temperature oxidation on the hydrogen in coal and the change of weight of coal in drying, by S. H. Katz and H. C. Porter. 1917. 16 pp., 2 figs.

TECHNICAL PAPER 123. Notes on the uses of low-grade fuel in Europe, by R. H. Fernald. 1915. 37 pp., 4 pls., 4 figs.

TECHNICAL PAPER 133. Directions for sampling coal for shipment or delivery, by G. S. Pope. 1917. 15 pp., 1 pl.

TECHNICAL PAPER 137. Combustion in the fuel bed of hand-fired furnaces, by Henry Kreisinger, F. K. Ovitz, and C. E. Augustine. 1916. 76 pp., 2 pls., 21 figs.

TECHNICAL PAPER 148. The determination of moisture in coke, by A. C. Fieldner and W. A. Selvig. 1917. 13 pp.

TECHNICAL PAPER 170. The diffusion of oxygen through stored coal, by S. H. Katz. 1917. 49 pp., 1 pl., 27 figs.

TECHNICAL PAPER 172. Effects of moisture on the spontaneous heating of stored coal, by S. H. Katz and H. C. Porter. 1917. 25 pp., 1 pl., 8 figs.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl., 7 figs. 10 cents.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp. 5 cents.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp., 4 pls., 7 figs. 10 cents.

BULLETIN 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911. 32 pp., 19 figs. 5 cents.

BULLETIN 9. Recent development of the producer-gas power plant in the United States, by R. H. Fernald. 1910. 82 pp., 2 pls. 15 cents.

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BULLETIN 11. The purchase of coal by the Government under specifications, with analyses of coal delivered for the fiscal year 1908–9, by G. S. Pope. 1910. 80 pp. 10 cents.

BULLETIN 13. Résumé of producer-gas investigations, October 1, 1904, to June 30, 1910, by R. H. Fernald and C. D. Smith. 1911. 393 pp., 12 pls., 250 figs. 65 cents.

BULLETIN 14. Briquetting tests of lignite at Pittsburgh, Pa., 1908–9, with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 64 pp., 11 pls., 4 figs. 15 cents.

BULLETIN 18. The transmission of heat into steam boilers, by Henry Kreisinger and W. T. Ray. 1912. 180 pp., 78 figs. 20 cents.

BULLETIN 21. The significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 64 pp., 26 figs. 10 cents.

BULLETIN 22. Analyses of coals in the United States, with descriptions of mine and field samples collected between July 1, 1904, and June 30, 1910, by N. W. Lord, with chapters by J. A. Holmes, F. M. Stanton, A. C. Fieldner, and Samuel Sanford. 1912. Part I, Analyses, pp. 1–321; Part II, Descriptions of samples, pp. 321–1129. 85 cents.

BULLETIN 23. Steaming tests of coals and related investigations, September 1, 1904, to December 31, 1908, by L. P. Breckenridge, Henry Kreisinger, and W. T. Ray. 1912. 380 pp., 2 pls., 94 figs. 50 cents.

BULLETIN 27. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 44 pp., 3 pls., 2 figs. 10 cents.

BULLETIN 30. Briquetting tests at the United States fuel-testing plant, Norfolk, Va., 1907–8, by C. L. Wright. 41 pp., 9 pls. 15 cents.

BULLETIN 31. Incidental problems in gas-producer tests, by R. H. Fernald, C. D. Smith, J. K. Clement, and H. A. Grine. 1911. 29 pp., 8 figs. 5 cents.

BULLETIN 33. Comparative tests of run-of-mine and briquetted coal on the torpedo boat *Biddle*, by W. T. Ray and Henry Kreisinger. 50 pp., 10 figs. 15 cents.

BULLETIN 34. Tests of run-of-mine and briquetted coal in a locomotive boiler, by W. T. Ray and Henry Kreisinger. 33 pp., 9 figs. 5 cents.

BULLETIN 35. The utilization of fuel in locomotive practice, by W. F. M. Goss. 29 pp., 8 figs. 5 cents.

BULLETIN 37. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests, and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1911. 58 pp., 4 pls., 35 figs. 15 cents.

BULLETIN 40. The smokeless combustion of coal in boiler furnaces, with a chapter on central heating plants, by D. T. Randall and H. W. Weeks. 1912. 188 pp., 40 figs. 20 cents.

BULLETIN 41. Government coal purchases under specifications, with analyses for the fiscal year 1909–10 by G. S. Pope, with a chapter on the fuel-inspection laboratory of the Bureau of Mines, by J. D. Davis. 1912. 97 pp., 3 pls., 9 figs. 15 cents.

BULLETIN 63. Sampling coal deliveries and types of Government specifications for the purchase of coal, by G. S. Pope. 1913. 68 pp., 4 pls., 3 figs. 10 cents.

BULLETIN 109. Operating details of gas producers, by R. H. Fernald. 1916. 74 pp. 10 cents.

BULLETIN 116. Methods of sampling delivered coal, and specifications for the purchase of coal for the Government, by G. S. Pope. 1916. 64 pp., 5 pls., 2 figs. 15 cents.

TECHNICAL PAPER 1. The sampling of coal in the mine, by J. A. Holmes. 1911. 18 pp., 1 fig. 5 cents.

TECHNICAL PAPER 20. The slagging type of gas producer, with a brief report of preliminary tests, by C. D. Smith. 1912. 14 pp., 1 pl. 5 cents.

TECHNICAL PAPER 63. Factors governing the combustion of coal in boiler furnaces, a preliminary report, by J. K. Clement, J. C. W. Frazer, and C. E. Augustine. 1914. 46 pp., 26 figs. 10 cents.

TECHNICAL PAPER 65. A study of the oxidation of coal, by H. C. Porter. 1914. 30 pp., 12 figs. 5 cents.

TECHNICAL PAPER 114. Heat transmission through boiler tubes, by Henry Kreisinger and F. K. Ovitz. 1915. 36 pp., 23 figs. 10 cents.